Prediction of Wind Farm Power and Ramp Rates: A Data-Mining Approach

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Outline

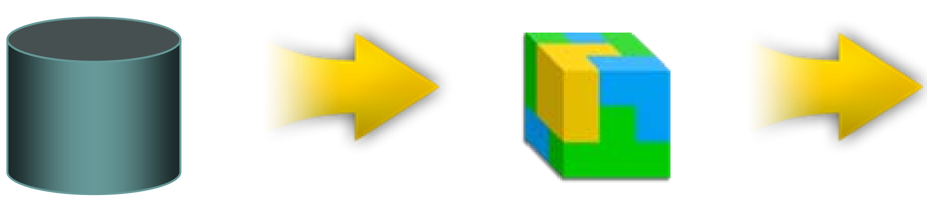
- ✓ What is data mining?
- ✓ Prediction of wind farm power: Operational horizon
- ✓ Short term power prediction
- ✓ Long term power prediction
- ✓ Prediction of power ramp rates
- ✓ Conclusion

What is Data Mining?

Data farming

A process

- ✓ Domain understanding
- ✓ Data selection
- ✓ Preprocessing, e.g., integration of different files
- ✓ Data transformation
- ✓ Pattern (knowledge) discovery
- ✓ Interpretation (e.g., visualization)
- ✓ Reporting



Knowledge

Learning Systems (1)

- ✓ Classical statistical methods (e.g., discriminant analysis)
- ✓ Modern statistical techniques (e.g., *k*-nearest neighbor, Bayes algorithm)
- ✓ Neural networks
- ✓ Support vector machines
- ✓ Decision tree algorithms
- ✓ Decision rule algorithms
- ✓ Learning classifier systems

Knowledge discovery

Black box tools

Learning Systems (2)

- ✓ Association rule algorithms
- ✓ Text mining algorithms
- ✓ Meta-learning algorithms
- ✓ Inductive learning programming
- ✓ Sequence learning

Data Mining: A New Paradigm

- ✓ An individual object (e.g., a state, a process) orientation

  vs.

- ✓ A population of objects orientation

Paradigm shift

- ✓ No old luggage
- ✓ Any number and type parameters
- ✓ Bottom up vs. top down
- ✓ Pull vs. push

Data Mining: Example

Training data set (SCADA data)

Time	WS_1	Tag_1	WS-2	Tag_2	Power_Status
1	4.02	Red	4.8	High	On_Target
2	7.03	Black	4.4	Low	Off_Target
3	9.9	Blue	12.4	High	On_Target
4	20.03	Blue	7.11	High	On_Target
5	13.0	Orange	6.96	Low	Off_Target
6	15.0	Blue	8.04	Medium	Off_Target
7	9.9	Orange	9.04	Medium	On_Target
8	10.2	Red	6.94	Low	Off_Target

$y = f(x)?$

Data Mining Model

Rule 1. (Tag_2 = High) => (Power_Status = On_Target);
[3, 3, 75.00%, 100.00%][{1, 3, 4}]

Rule 2. (Wind_Speed_2 >= 8.54) => (Power_Status = On_Target);
[2, 2, 50.00%, 100.00%][{3, 7}]

Rule 3. (Tag_2 = Low) => (Power_Status = Off_Target);
[3, 3, 75.00%, 100.00%][{2, 5, 8}]

Rule 4. (Wind_Speed_1 in [10.050, 17.515)) => (Power_Status = Off_Target);
[3, 3, 75.00%, 100.00%][{5, 6, 8}]

Decision Tree

On_Target

Tag_2 = High

Wind_Speed_2 >= 8.54

Off_Target

Tag_2 = Low

Wind_Speed_1 in [10.050, 17.515]

Parameter Reduction Concept

Initial number of parameters

[Large number]

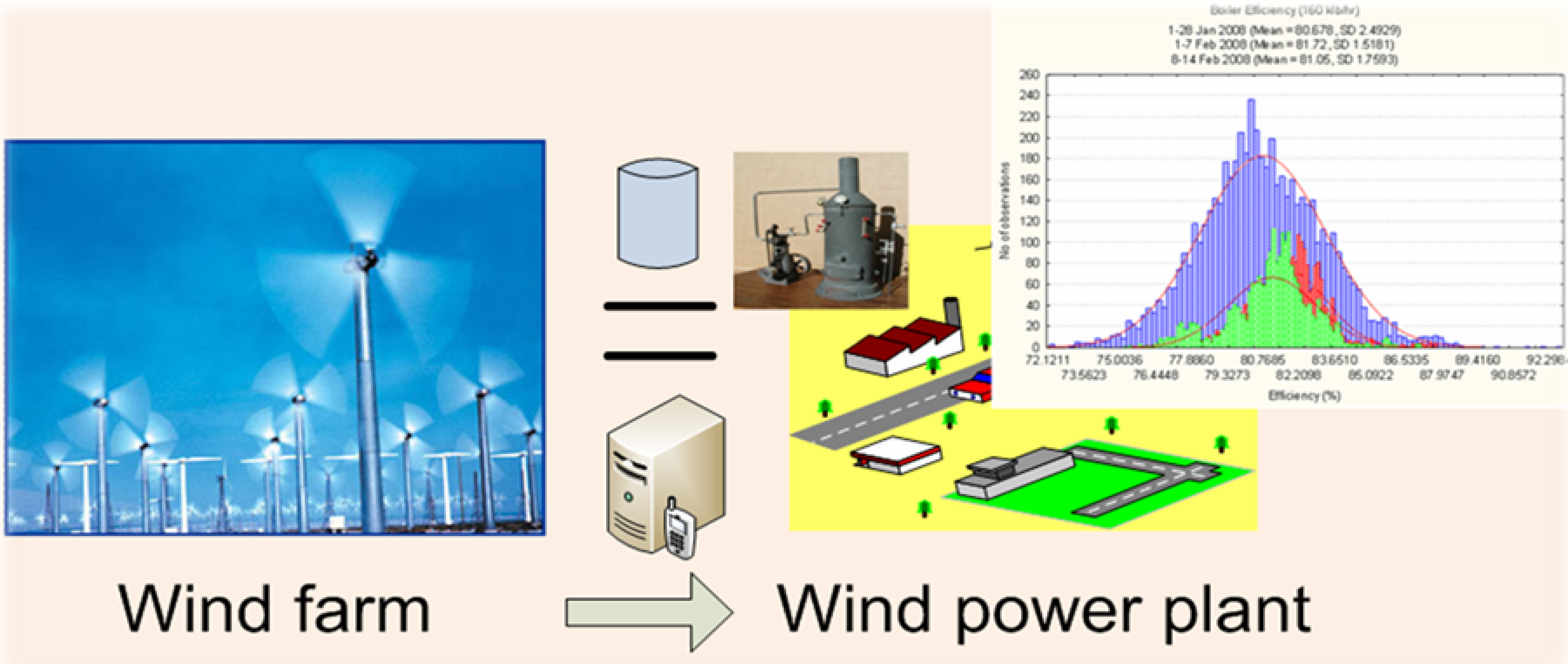
Data compression

Parameter selection algorithms
+ selection within learning algorithms

Final number of parameters

[Small number]

Predictive Engineering and Power Prediction



Prediction Accuracy Metrics

- ✓ *AE*: Absolute error (%) is the absolute difference between the predicted and actual power output, and it is expressed as the percentage of the rated power

$$AE = \frac{\left|\hat{y}(t+T) - y(t+T)\right|}{RP} \times 100\%$$

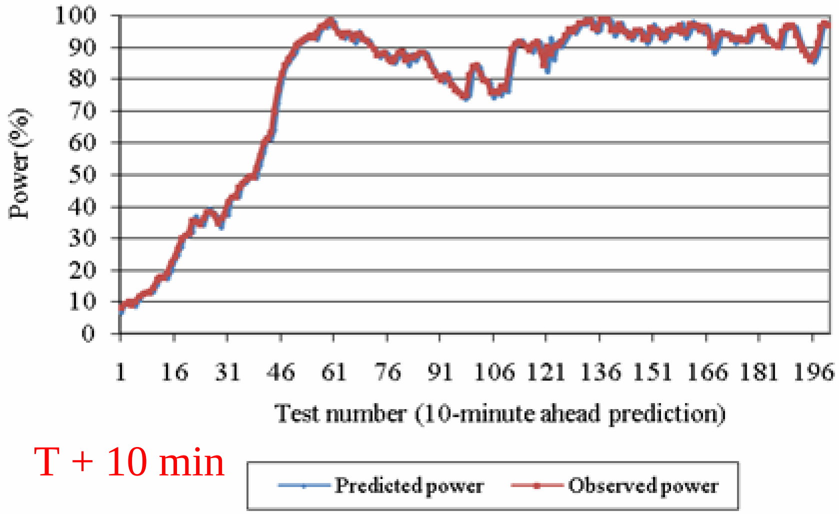
- ✓ *MAE*: Mean absolute error (%) is the average of the absolute error over a particular data set

$$MAE = \frac{\sum_{i=1}^{N} AE(i)}{N}$$

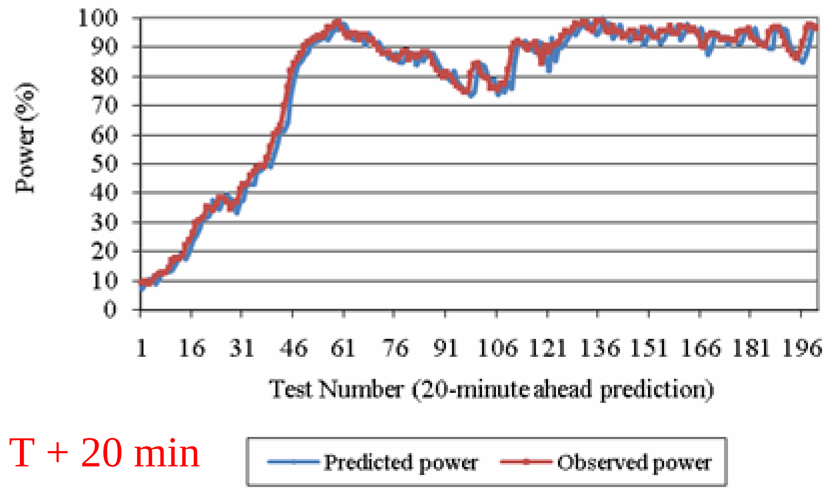
- ✓ *STD*: The standard deviation (%) of the *AE*

$$Std = \sqrt{\frac{\sum_{i=1}^{N} (AE(i) - MAE)}{N-1}}$$

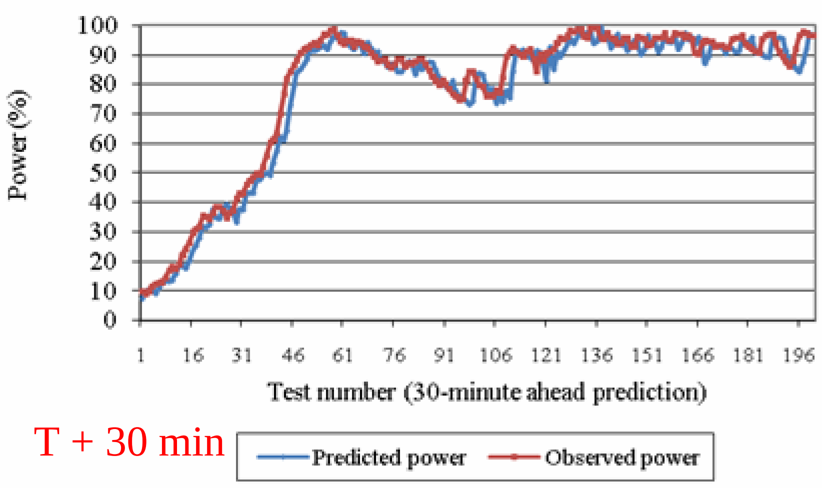
Power Prediction Accuracy



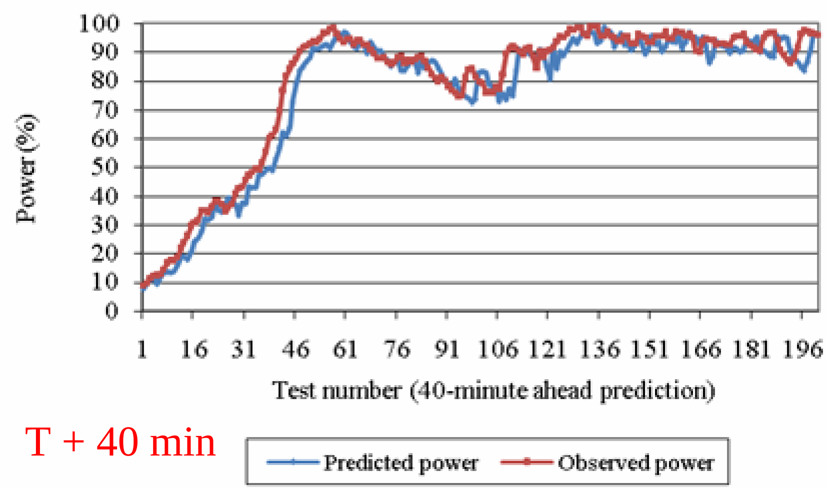
T + 10 min



T + 20 min



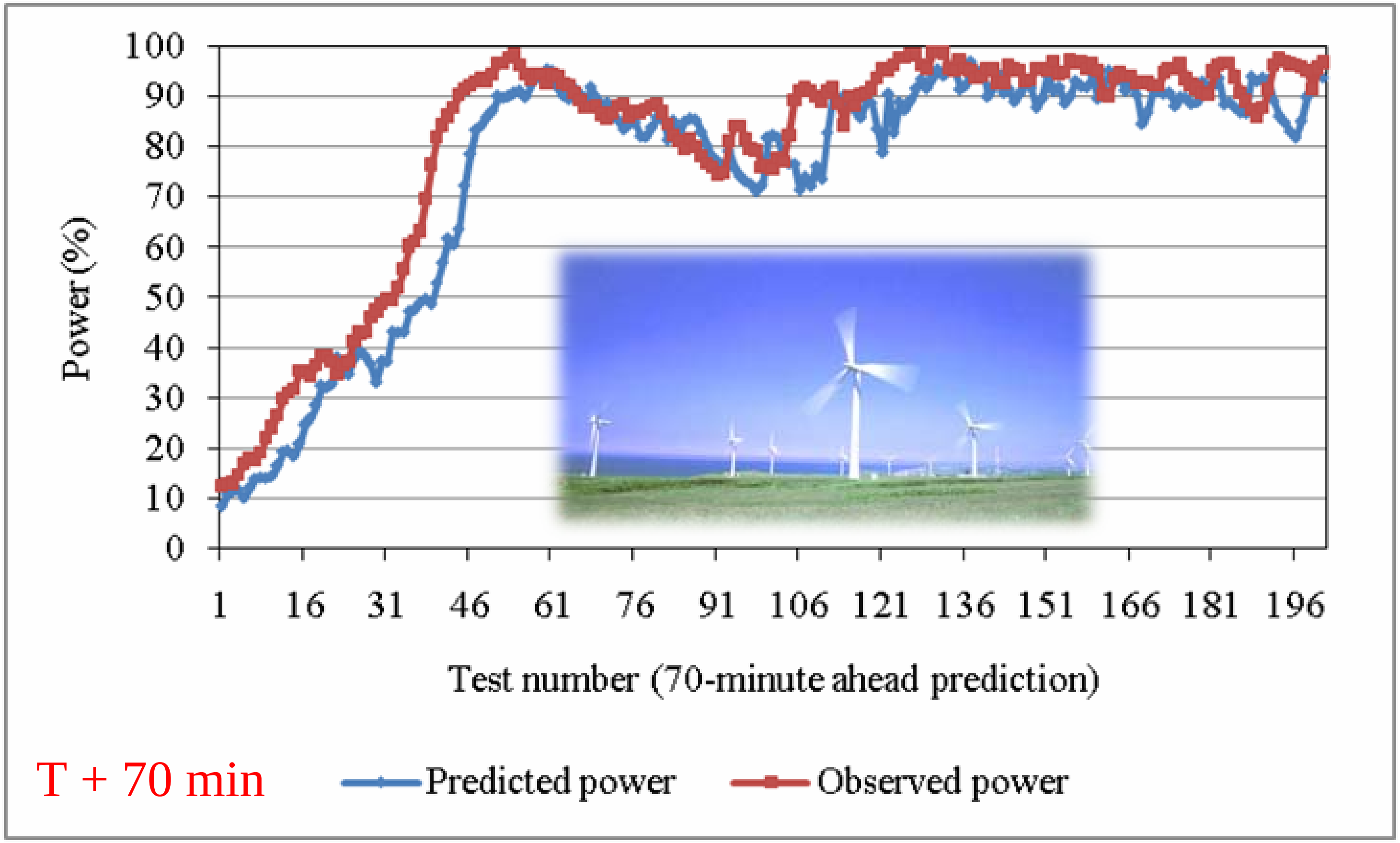
T + 30 min



T + 40 min

Operational horizon

Power Prediction Accuracy



Operational horizon

T + 10*n* Minute Predictions

Time	MAE (%)	STD (%)
T + 10 min	2.213	2.501
T + 20 min	3.912	4.083
T + 30 min	5.143	5.149
T + 40 min	6.062	5.917
T + 50 min	6.721	6.567
T + 60 min	7.384	6.987
T + 70 min	8.025	7.514

Operational horizon

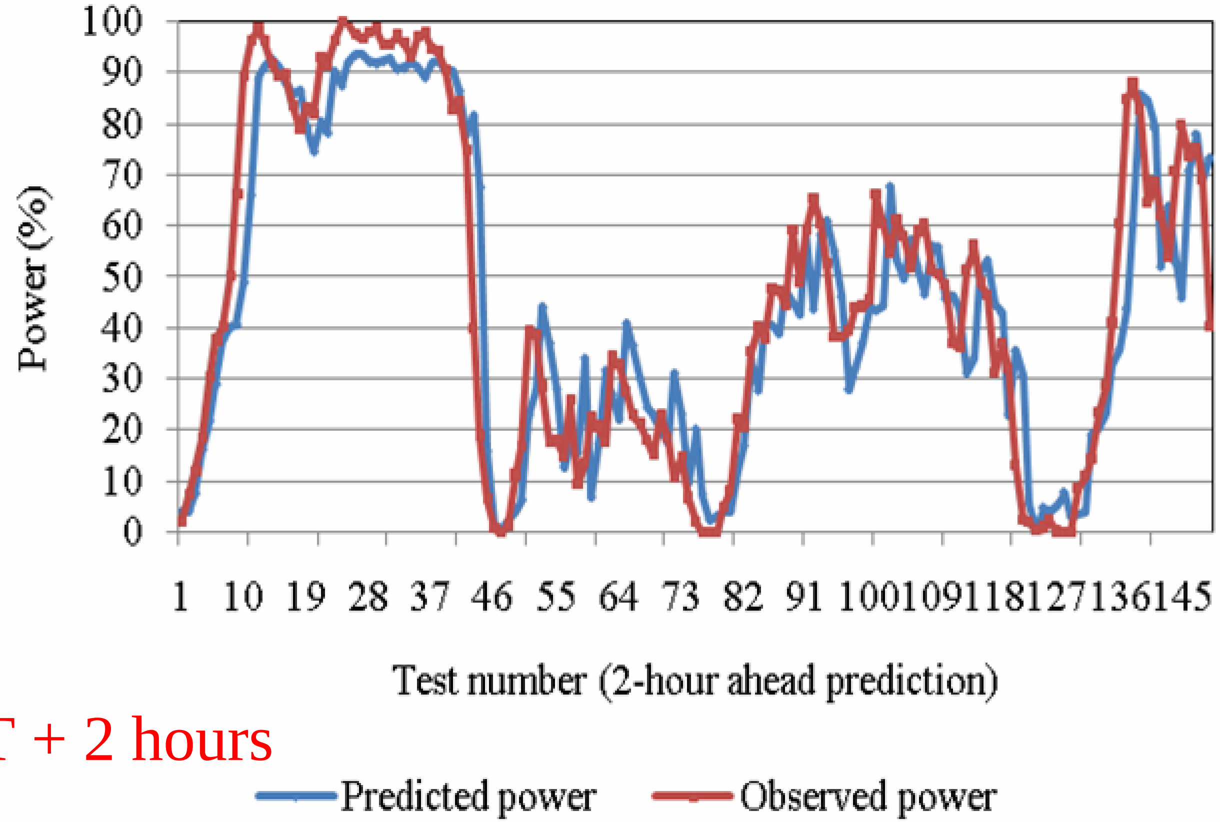
T + *n* Hour Power Predictions

Time	MAE (%)	STD (%)
T + 1	5.850997	5.654549
T + 2	9.336708	8.916529
T + 3	11.82863	11.23414
T + 4	14.99185	13.20335

Time	MAE (%)	STD (%)
T + 1	8.183	7.744
T + 2	13.452	10.948
T + 3	15.488	13.683
T + 4	19.626	16.481

Short term horizon

Hourly Power Predictions



T + 2 hours

Short term horizon

Short Term Predictions

Time	MAE (%)	STD (%)	Time	MAE (%)	STD (%)
T + 1	9.28	8.12	**T + 7**	9.82	9.19
T + 2	9.35	8.21	**T + 8**	10.57	9.91
T + 3	9.76	8.69	**T + 9**	8.41	8.73
T + 4	9.36	8.32	**T + 10**	11.06	10.63
T + 5	9.97	8.93	**T + 11**	11.19	9.08
T + 6	10.49	9.99	**T + 12**	11.49	10.53

Time	MAE(%)	STD (%)	Time	MAE (%)	STD (%)
T + 1	10.32	9.14	**T + 7**	11.89	9.89
T + 2	10.14	8.78	**T + 8**	15.57	12.91
T + 3	10.88	9.49	**T + 9**	11.59	10.43
T + 4	11.17	9.52	**T + 10**	11.62	11.09
T + 5	15.97	12.63	**T + 11**	12.19	11.69
T + 6	10.92	10.44	**T + 12**	12.49	10.81

Long Term Predictions

Time	MAE (%)	STD (%)	Time	MAE (%)	STD (%)
T + 3	5.93	4.23	**T + 45**	12.87	10.23
T + 9	9.12	8.91	**T + 51**	10.97	10.92
T + 15	9.92	8.04	**T + 57**	13.82	9.61
T + 21	9.39	7.28	**T + 63**	11.88	9.95
T + 27	10.35	6.41	**T + 69**	9.56	7.68
T + 33	11.81	12.24	**T + 75**	10.83	9.32
T + 39	11.63	7.79	**T + 81**	6.37	6.19
T + 42	11.49	10.06	**T + 84**	10.57	8.78

Time	MAE (%)	STD (%)	Time	MAE (%)	STD (%)
T + 3	9.52	8.01	**T + 45**	16.81	13.13
T + 9	14.67	12.07	**T + 51**	13.47	12.58
T + 15	9.58	8.53	**T + 57**	15.91	11.38
T + 21	11.52	12.32	**T + 63**	18.04	12.73
T + 27	19.11	14.03	**T + 69**	13.54	12.72
T + 33	13.77	13.16	**T + 75**	15.04	9.89
T + 39	16.33	9.72	**T + 81**	10.71	8.79
T + 42	12.15	10.24	**T + 84**	10.99	11.31

Definition: Power Ramp Rate

- ✓ *PRR*: Power ramp rate is the degree of power change over time interval *T*

$$PRR = \frac{P(t+T) - P(t)}{T} \quad \text{[kW/min]}$$

$$PRR = \frac{P(t+T) - P(t)}{T \times RP} \times 100\% \quad \text{[\%/min]}$$

- ✓ *t* : The current time
- ✓ *RP*: Rated power of the wind farm

PRR Prediction Metric

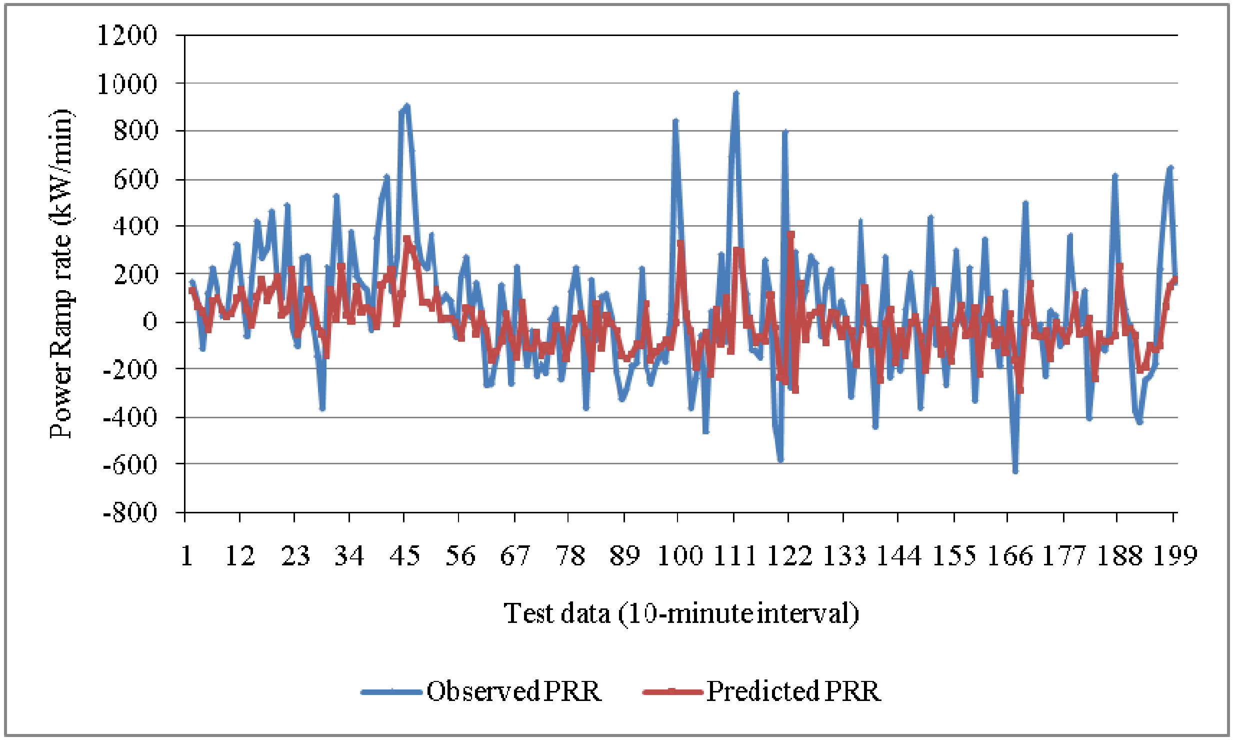
✓ *AE*: Absolute error [kW/min or %/min]

$$AE = \left| y - \hat{y} \right|$$

✓ y is the observed *PRR*

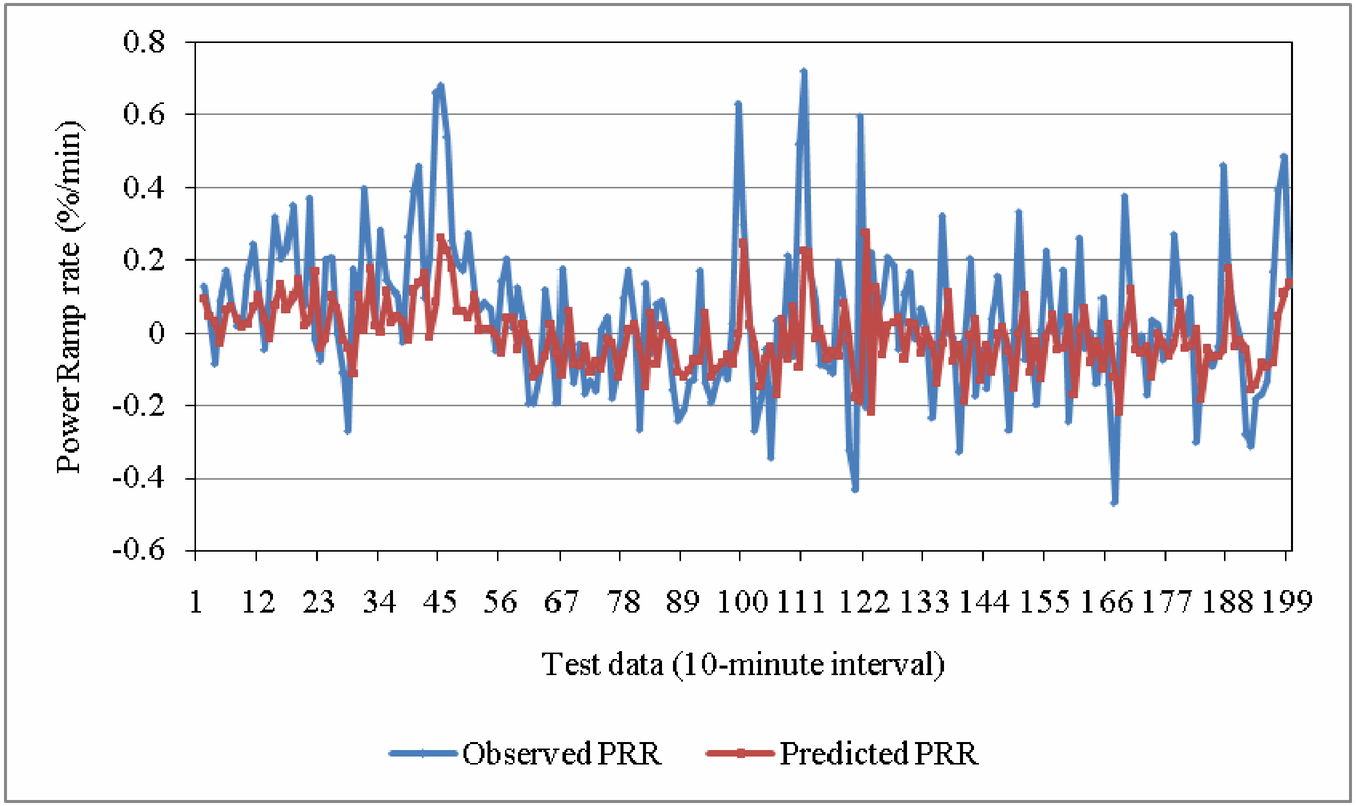
✓ $\hat{y}$ is the predicted *PRR*

T + 10 min PRR Prediction



PRR is in kW/min

T + 10 min PRR Prediction



PRR is in %/min

T + 10 min PRR Prediction

AE	kW/min	%/min
Mean	298.927	0.224
Std	337.855	0.253
Max	3556.387	2.6634
Min	0.016	0

Summary of AE = Absolute Error

AE for the Positive PRR

AE	kW/min	%/min
Mean	289.662	0.217
Std	321.009	0.241
Max	2470.376	1.850
Min	0.0156	0

AE for the Negative PRR

AE	kW/min	%/min
Mean	309.881	0.232
Std	356.837	0.267
Max	3556.387	2.664
Min	4.458	0.003

PRR AE for the Top 15% of Wind Farm Rated Power

AE	kW/min	%/min
Mean	191.701	0.144
Std	183.894	0.138
Max	1091.341	0.817
Min	0.016	0

PRR AE for the Mid-range 20% of Wind Farm Rated Power

AE	kW/min	%/min
Mean	467.627	0.351
Std	481.195	0.361
Max	3556.387	2.664
Min	8.131	0.006

PRR AE for the Bottom 15% of Wind Farm Rated Power

AE	kW/min	%/min
Mean	111.541	0.083
Std	132.699	0.099
Max	954.421	0.715
Min	1.011	0.001

Conclusions

- ✓ The accuracy of the model for power prediction over an operational horizon is sensitive to the horizon length
- ✓ The prediction accuracy is satisfactory for up to 60 minutes into the future and it can be further improved
- ✓ The prediction error of the model based on weather forecasting data has no obvious tendency to increase as the prediction horizon lengthens

Conclusions

- ✓ The more accurate the weather forecasting data, the better quality of the short and long term power prediction model
- ✓Building power prediction models based on weather forecasting data is more computer intensive than building models based on the wind farm data

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